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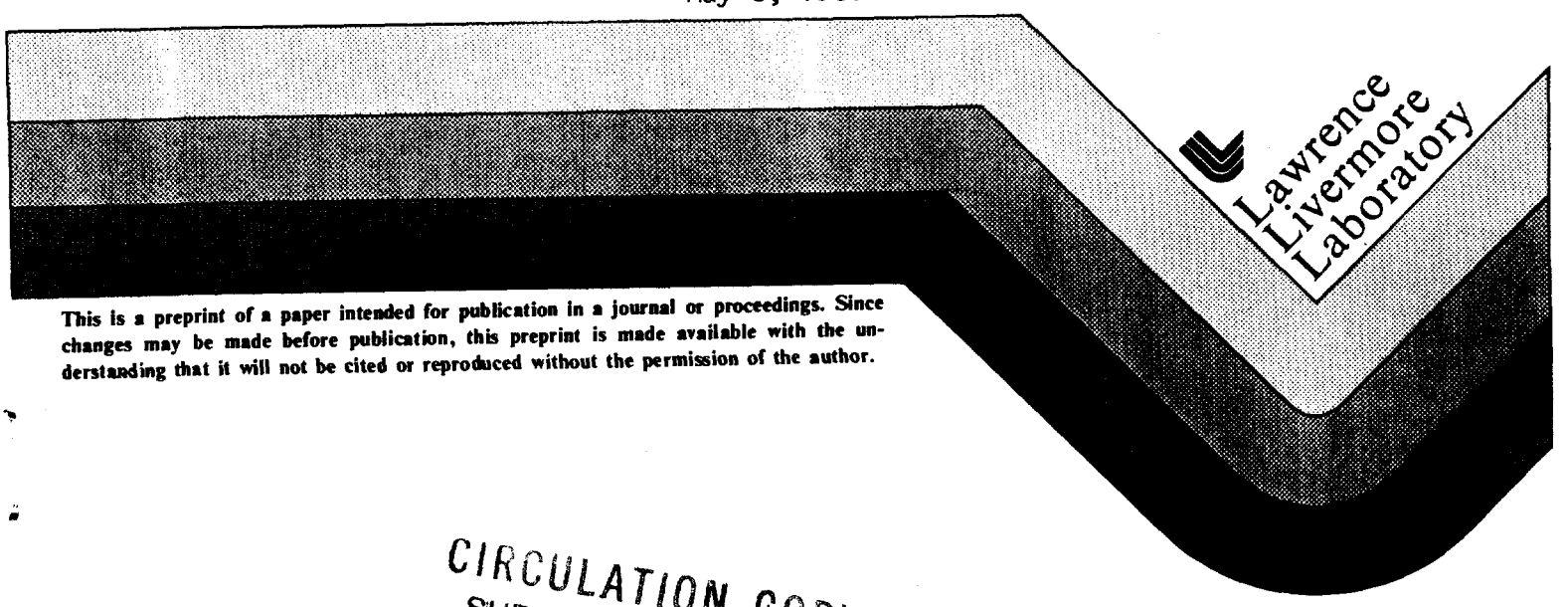

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A STUDY OF OPTICAL MODEL PARAMETERS FOR HIGH ENERGY NEUTRON CROSS SECTIONS FROM 5 - 50 MeV IN THE MASS-140 REGION

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ABSTRACT

We have begun a study of the neutron optical potential on nuclei near mass-140. In this study we are extending the energy range and improving the precision of previous neutron total cross section measurements. The extended energy range of this measurement reveals maxima and minima in the total cross section which are evidence of the nuclear Ramsauer effect. We employ the 100-MeV linear accelerator to produce a continuum of neutron energies from a Ta-Be conversion target. We use the 250-meter flight path and measure neutron energies by the time-of-flight method. We have obtained transmission data for ^{140}Ce and transmission ratios for ^{142}Ce, ^{141}Pr, and ^{139}La relative to ^{140}Ce. The ^{140}Ce data have a precision of 1-3% and the ratios are obtained with a precision of about .3%. To analyze these total cross section data a computer code has been developed to calculate the total elastic, reaction, and differential elastic scattering cross sections of a neutron interacting with a nucleus. The interaction is represented by a spherically symmetric complex potential which includes spin-orbit coupling. The parameters of this potential have been adjusted to approximate the ^{140}Ce total cross over the energy range from 2.5 to 60 MeV. The energy dependence of these parameters will be described.

INTRODUCTION

Nuclear cross sections which have not been measured are often required to predict the behavior of neutrons in the materials of fusion or fission reactors. In many cases the optical model is

called on to predict these cross sections or model the nucleon-nucleus interaction involved in producing an unmeasured nuclear reaction. An improved understanding of the variation of optical model parameters with energy and nucleon number will increase our confidence in these predictions. As part of a study of the neutron optical model potential we have measured the neutron total cross section of ^{140}Ce and the total cross section ratios for ^{142}Ce, ^{141}Pr, and ^{139}La relative to ^{140}Ce. These measurements were made over an extended energy range with high precision to test the predictions of the optical model. The level of precision, 1-3% in cross section and .3% in ratio, was chosen after using current optical model predictions for nuclei in this mass region to predict the difference for adjacent isotopes. The energy range was chosen to cover two nuclear Ramsauer[1] minima in the cross section. The nuclear Ramsauer effect is due to destructive and constructive interferences between neutron waves transmitted through the nucleus and those diffracted around it. With this energy range and precision we expect to provide a stringent test of the optical model. If it performs well we hope to extract information on the nuclear matter distribution. Since these measurements were only recently completed and the optical model analysis is still in progress, only preliminary conclusions can be drawn on these points.

EXPERIMENT

Considerable care was taken with all facets of experimental technique to achieve high precision over a wide range in energy. The 100 MeV LLL linac provided a contiuum of neutron energies which allowed us to measure the neutron transmission at all energies simultaneously. This source was pulsed at 1440 pps for 10 nanoseconds duration. Neutron energies were determined by the time-of-flight technique over a 250 meter flight path which gave more than adequate energy resolution. This long flight path was used primarily to minimize the background contribution at high energies (i.e. short flight-times) produced by the detector response to the gamma-flash in the neutron target. This background as well as the energy of the accelerator set the upper limit of our energy range.

The detector design was chosen to minimize its response to the gamma flash and maximize its efficiency for high energy neutrons. This design consisted of 16 independent plastic scintillators (each 25 cm x 25 cm x 5 cm) stacked two (2) high and eight (8) deep. A view of the time-of-flight facility is shown in Fig. 1. The neutron producing target was made of water-cooled beryllium plates following a tantalum radiator which converted the electron flux to photons. This target was shown to produce a factor of six (6) improvement in high energy (>10 MeV) neutron flux in comparison with a tantalum neutron target used in other measurements. A study was also made of filters used to reduce the

gamma flash response in the neutron detector. For $^{140}Ce/H$ measurements a 3 cm tungsten filter was required. In the case of the ratio measurements only 1 cm was necessary. The availability or limited quantities of separated isotopes made it necessary to use tight (1 cm dia.) collimation of the neutron beam at the sample position. Powdered oxide targets were prepared by weighing the samples accurately and packing them in hollow aluminum rods milled to precisely the same inside diameter. The ^{140}Ce total cross section was obtained by measuring its transmission relative to hydrogen using an H_2O sample. In all cases the ratio of target thicknesses was chosen to exactly cancel the oxygen contribution in the transmission ratio. The target thicknesses were chosen to give a transmission of $\sim e^{-1}$. This choice minimizes the time needed to achieve a given statistical accuracy at a fixed data rate.

Data rates were limited to one count in ten beam bursts to minimize uncertainties inherent in large dead time corrections. The samples in each ratio measurement were alternately cycled into the neutron beam under computer control. The exposure period was determined by the number of neutron events observed in a monitor detector on a separate neutron flight path as shown in Fig. 1 This cycle length was adjusted to be about 10 minutes to average out systematic variations in the neutron production rate at the source which were not accounted for on the neutron monitor. Neutron flight times were measured by a time digitizer with minimum time resolution set at 4 nanoseconds per channel. Time-of-flight spectra and monitor data were recorded in computer memory for each sample for one cycle. After all samples were exposed, the spectra were recorded on disk, memory was cleared and a new cycle begun. A cumulative spectrum for each sample was also collected to monitor the progress of the experiment. This method of data recording permitted us to discard cycles which had neutron or monitor rates substantially outside the normal statistical fluctuations.

RESULTS

These data were corrected for dead time losses and background events and analyzed to obtain total cross sections or cross section differences. The $^{140}Ce/H$ ratio was analyzed to give the total cross section for ^{140}Ce by using previous measurements of the H cross section.[2] At low neutron (<10 MeV) energies the H cross section is large and contributes about 1% to the uncertainty in the ^{140}Ce total cross section. This uncertainty drops to .2% by 50 MeV and at these energies the uncertainty is dominated by background and statistics.

In Fig. 2 the unfolded cross section of ^{140}Ce is presented. The verticle bars represent the statistical error only. Fig. 3 presents the ^{142}Ce-^{140}Ce cross section difference. In the overlap region of the low and high energy runs these difference cross

sections overlap within statistics. This reproducibility gives us increased confidence in this experimental technique.

OPTICAL MODEL ANALYSIS

A spherically symmetric optical model applicable to these nuclei near a closed shell (N=82) was used to describe these results.

The form of the potential chosen was typical of some optical models,[3] i.e.

$$V_{om} = V_o\, f_1(r) + i\, Wo\, f_2(r) + V_s \left(\frac{\hbar}{M_{\pi_o} C}\right)^2 \left|\frac{1}{r}\frac{df_1}{dr}\right| \bar{\sigma}\cdot\bar{\ell}$$

where $$f_1(r) = 1 + e^{\left(\frac{r-R}{a}\right)} - 1$$

$$R = 1.26\, A^{1/3}\, f$$

$$a = 0.7_f$$

and $$f_2(r) = e^{-\left[\frac{r-R}{b}\right]^2} \quad b = 1_f .$$

The calculational procedures used in this study are described elsewhere.[4]

This form of the optical model potential was used in the analysis of neutron total cross sections for a wide range of nuclear masses at 14 MeV by Dukarevich et. al.[5] In our case we cover an extended range of neutron energies which must be accounted for by dependence in the optical model parameters on energy. This energy dependence comes in part from an intrinsic energy dependence in the nucleon interaction and Buck[6] and in part from the approximation of a non-local potential by an equivalent local potential. The energy dependence obtained in our preliminary fit to the ^{140}Ce total cross section is

Real part

$$V_o = -49.9 + 0.32E + (17.-0.111E)\,\frac{N-Z}{A} \text{ for } E<25 \text{ MeV}$$

$$V_o = -45.88 + 0.159E + (15.58-0.054E)\,\frac{N-Z}{A} \text{ for } E>25 \text{ MeV}$$

Imaginary part

$$W_o = -7.456 + 26\,\frac{N-Z}{A} - 1.4\,E \text{ for } E<5 \text{ MeV}$$

$$W_o = -16.32\,(1-e^{-E/2.3}) + 26\,\frac{N-Z}{A} \text{ for } E>5 \text{ MeV}$$

The fit to our total cross section data is illustrated in Fig. 4. This potential was also used to predict the angular distribution for elastic scattering of neutrons at 7 MeV from ^{142}Nd. Fig. 5 compares our prediction with recent experimental results of G. Haout et. al.[7] We also find our prediction of the total inelastic cross section to be in good agreement with the measurements of Owens and Towle.[8] This agreement is demonstrated in Table I. However we must emphasize the preliminary nature of this potential. If the difference between the optical model prediction described above and our data is compared with the ^{142}Ce-^{140}Ce difference of Figure 3 we find that they are about the same magnitude. Thus further adjustment of the optical model parameters will be necessary before conclusions can be drawn about its ability to predict the precision ratio data. In making such adjustments we will apply constraints dictated by recent theoretical studies[9] and other available data.

SUMMARY

Precision neutron total cross section data have been obtained over an energy range from 2.5 to 60 MeV for ^{140}Ce. Ratios for ^{142}Ce, ^{141}Pr, and ^{139}La relative to ^{140}Ce have been analyzed to determine the differences in these cross sections. A preliminary fit to the ^{140}Ce has been made using a spherically symmetric optical model. Further refinements will be necessary to determine the ability of the optical model to predict the cross section ratios within the constraints of theoretically and experimentally reasonable choices of optical model parameters.

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TABLE I.

Neutron Energy (MeV)	Optical Model Reaction Cross Section (barns)	Measured Cross Section (barns)
5.0	2.42	2.64 ± .11
6.0	2.40	2.40 ± .09
7.0	2.38	2.30 ± .14

FIGURE CAPTIONS

Fig. 1 Plan view of 250 meter T-O-F Facility

Fig. 2 Experimental total neutron cross section of ^{140}Ce

Fig. 3 Experimental difference of total neutron cross sections, ^{142}Ce-^{140}Ce. X-high detector threshold, O-low detector threshold

Fig. 4 A comparison of the Optical Model Prediction with the ^{140}Ce neutron total cross section

Fig. 5 A comparison of the Optical Model Prediction of the differential Elastic Scattering cross section with experimental data for ^{142}Nd

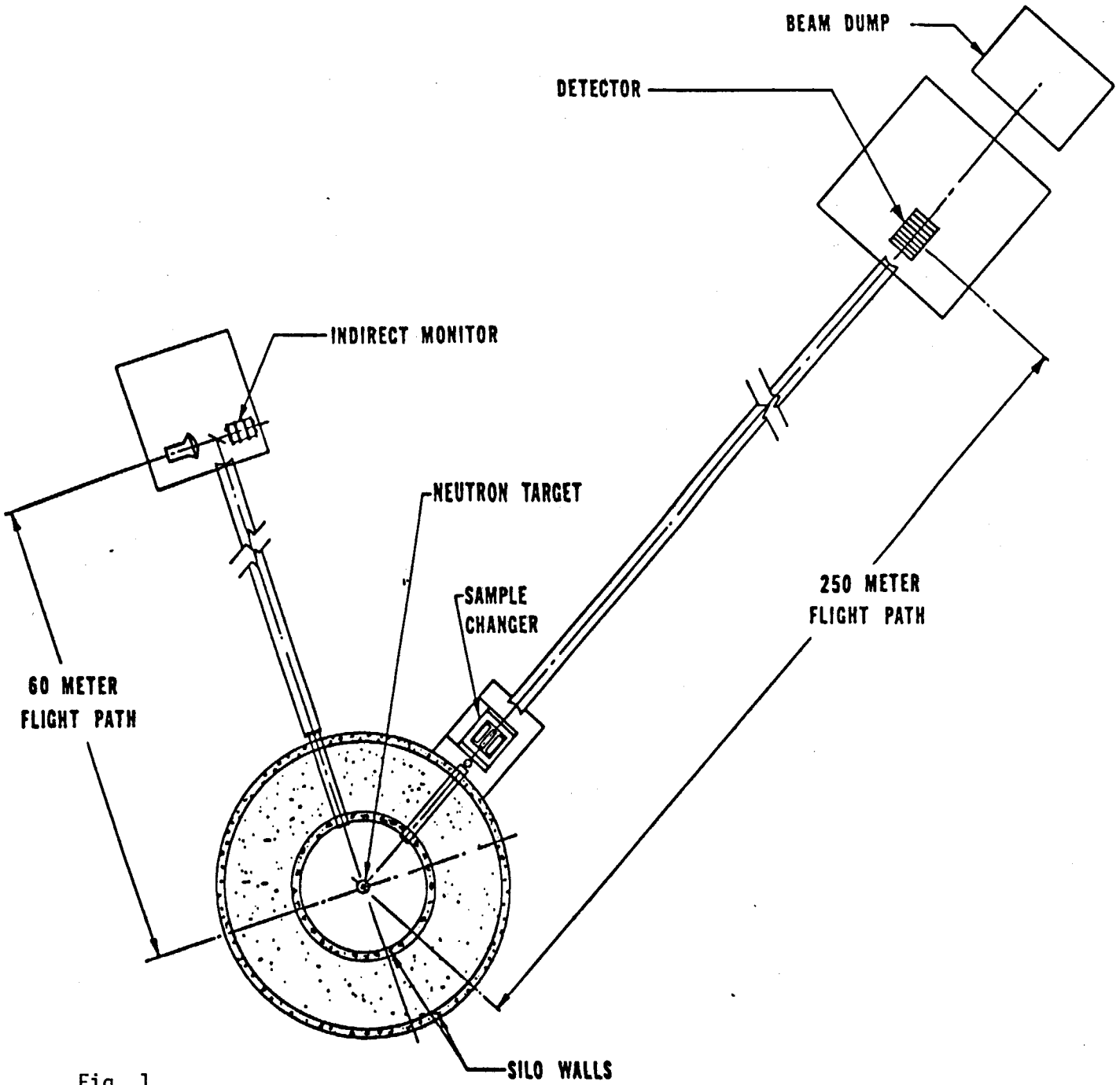
BEAM DUMP
DETECTOR
INDIRECT MONITOR
NEUTRON TARGET
SAMPLE CHANGER
250 METER FLIGHT PATH
60 METER FLIGHT PATH
SILO WALLS

Fig. 1

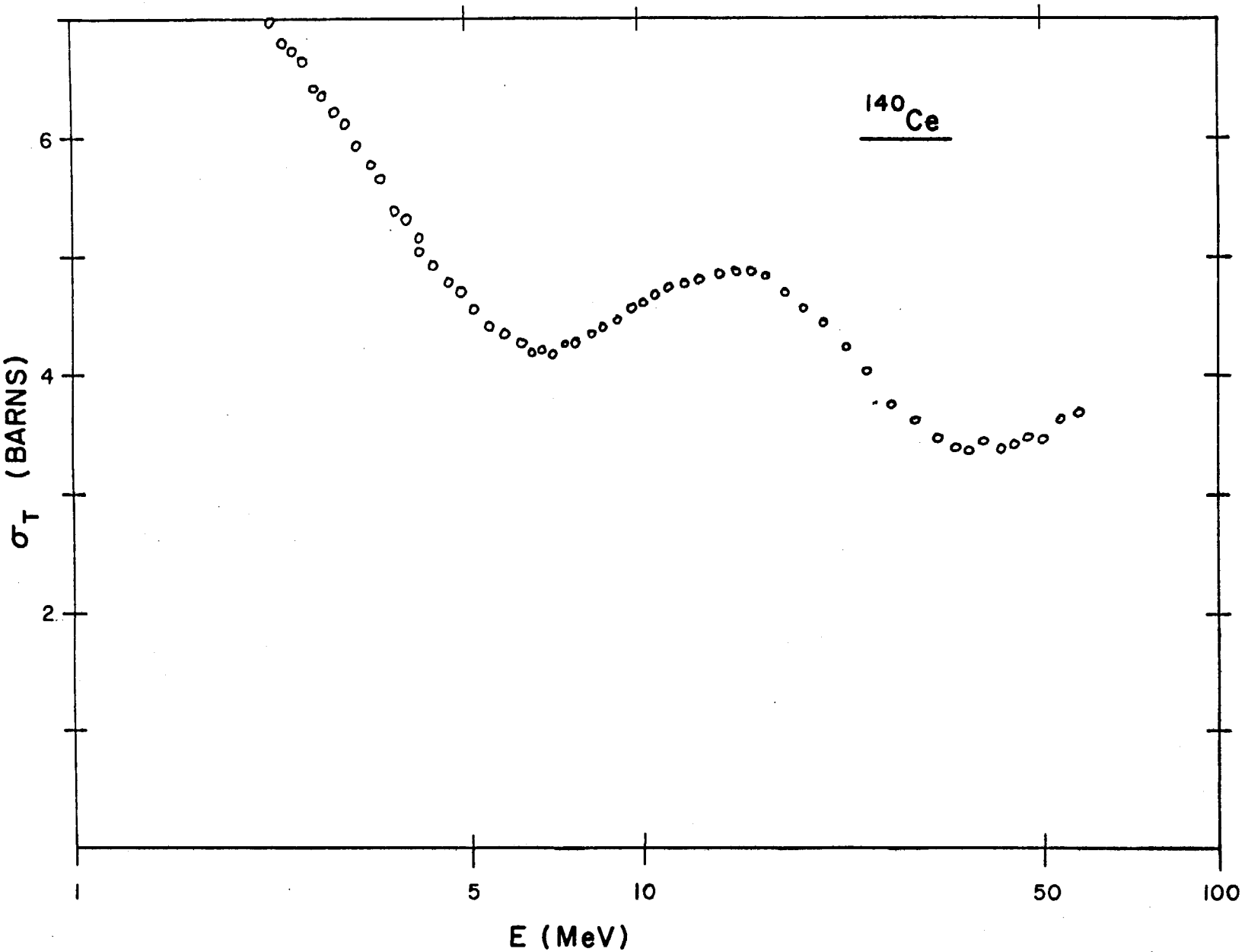

Fig. 2

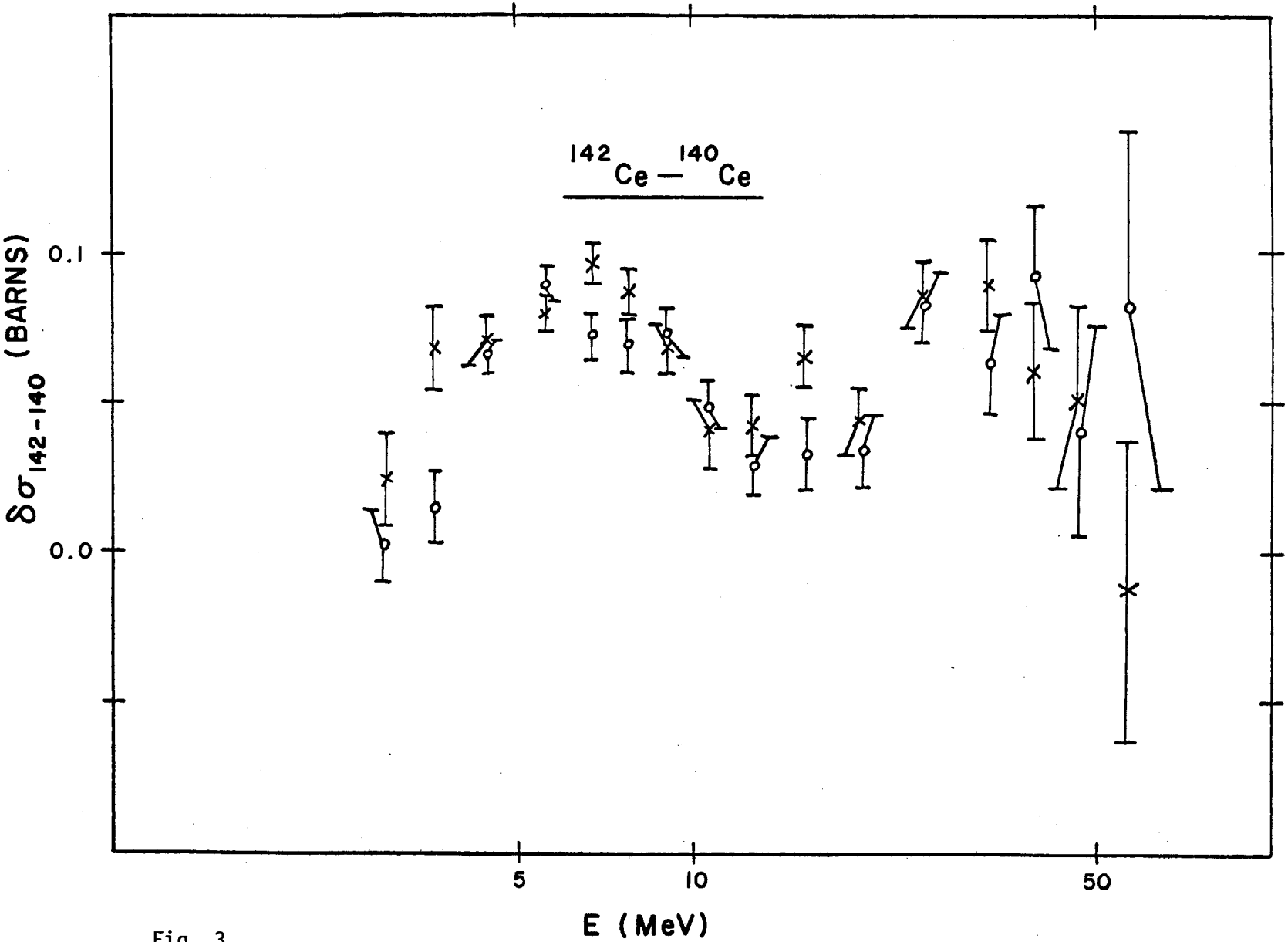

Fig. 3

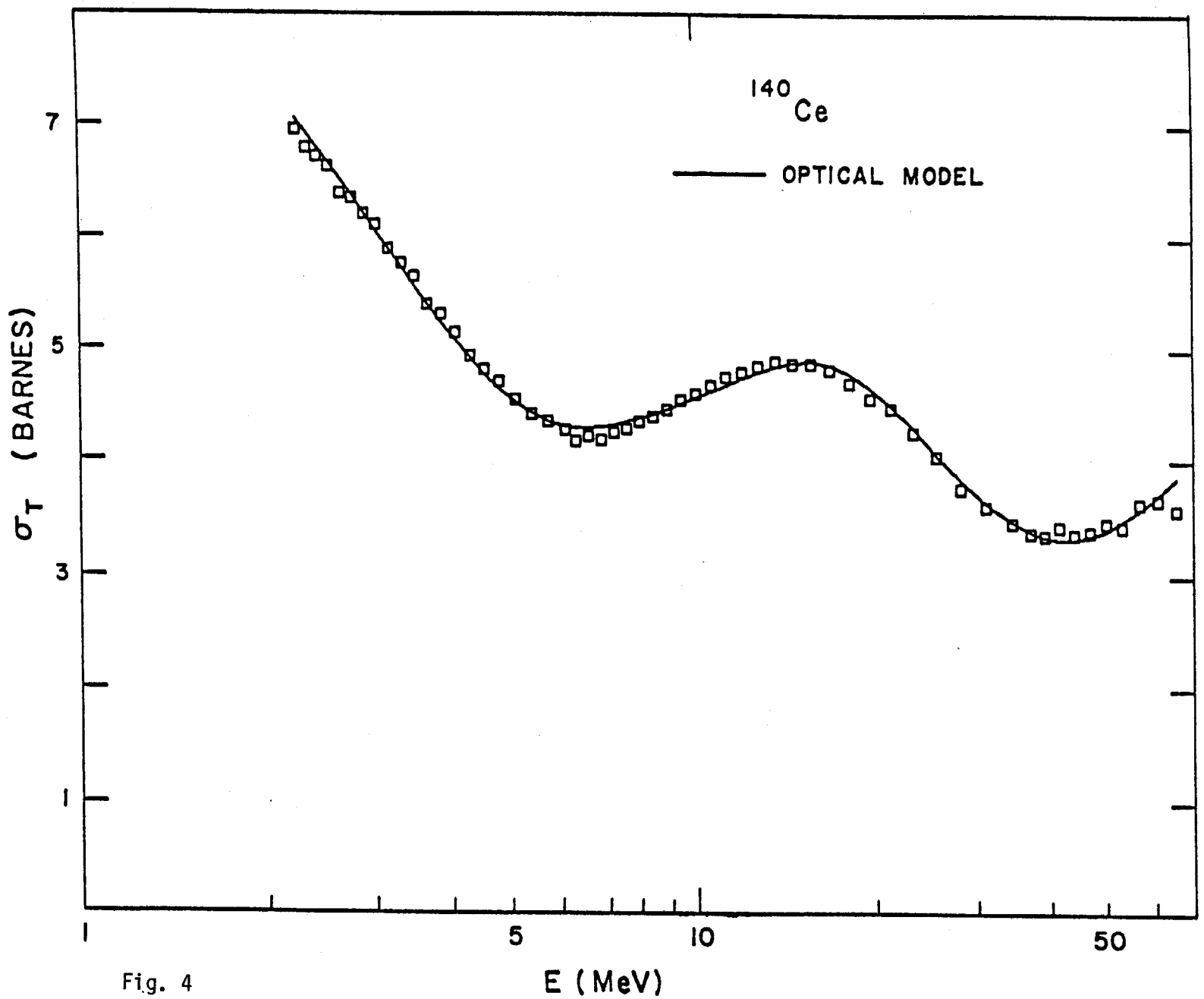

Fig. 4

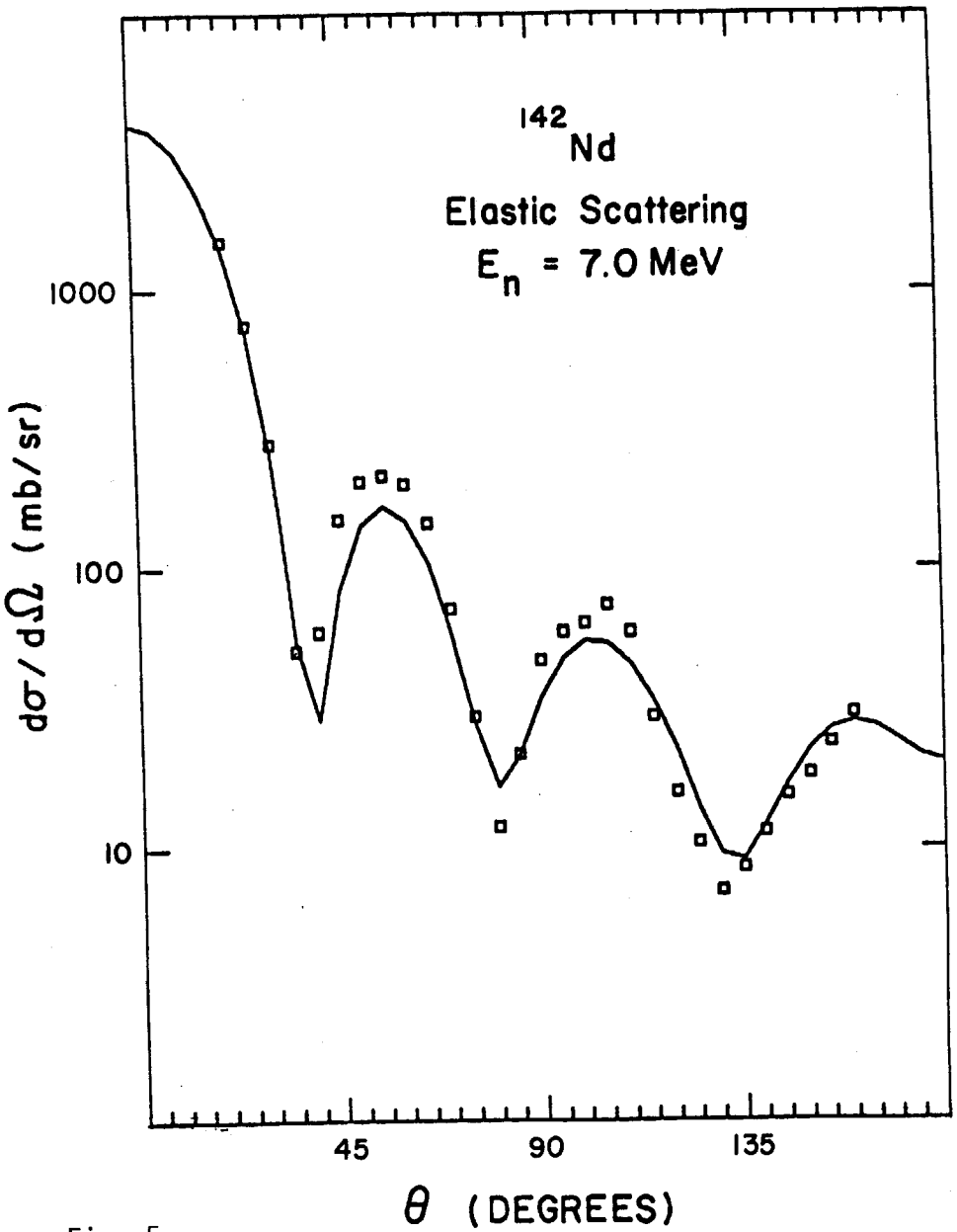
142 Nd
Elastic Scattering
E_n = 7.0 MeV
1000
100
10
dσ/dΩ (mb/sr)
45
90
135
θ (DEGREES)

Fig. 5